

## RECYCLING SYSTEM FOR A CHEMICAL LASER SYSTEM

### CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This application is a divisional of United States Patent  
5 Application No. 09/730,718 filed on December 6, 2000. The disclosure of which  
is incorporated herein by reference.

### FIELD OF THE INVENTION

**[0002]** The present invention relates generally to chemical laser  
10 systems, and more particularly to an improved system for collecting, reprocessing  
and recycling spent chemical species that are used by a chemical laser system.

### BACKGROUND OF THE INVENTION

**[0003]** The fact that an atom will emit a photon of radiation when one  
15 of its electrons drops to a lower energy state has enabled the laser to be employed  
in a number of military, industrial, and medical applications. The term "laser" is an  
acronym for light amplification by stimulated emission of radiation. In its simplest  
form, a laser consists of a rod of transparent crystal or a tube filled with gas or  
liquid. A reflecting mirror is placed at one end and a partially reflecting mirror at the  
20 other end. The laser is then pumped by adding energy, e.g., by shining another  
light source into it, by adding electrical energy, or by stimulating a chemical  
reaction. This process raises electrons in the laser to higher energy states.

**[0004]** During or subsequent to the pumping process, some of the  
electrons will spontaneously fall back to a lower energy state, emitting photons.  
25 The photons that travel toward the sides of the laser are quickly lost, but those  
traveling along the length of the rod or tube are reflected back by the mirrors. This  
activity generally occurs in the area commonly referred to as the laser gain region.  
When these photons strike other excited atoms, they stimulate those atoms to  
release photons of the exact same energy level (or wavelength), which travel in the  
30 same direction as the stimulating photons. The result is an intense, highly focused  
beam of light escaping through the half-silvered end of the laser. This light beam is  
generally referred to as a beam of coherent radiation, or more commonly, a laser  
beam.

[0005] Because the photon wavelength is determined by the characteristics of the atoms in the lasing material, laser light can be of a single wavelength. Because laser light travels in a tight beam, it can carry a great deal of energy over a great distance without significant loss. With respect to recent  
5 developments in laser technology, there has been increased interest in high-energy chemical laser systems.

[0006] Current high-energy chemical lasers can be classified as either: (1) hydrogen-halide lasers; or (2) chemical oxygen-iodine lasers (COIL). Hydrogen-halide lasers typically employ a reaction of hydrogen and/or deuterium  
10 with fluorine, chlorine, bromine or iodine in diluent gases of helium, nitrogen, or the like, to produce hydrogen and/or deuterium halide molecules in excited vibrational states from which laser energy can be extracted. Exhaust from the laser cavity of a hydrogen-halide laser is typically a mixture of gases at high temperature (up to 1000°C) including HF (and/or DF), He, N<sub>2</sub>, and possibly small amounts of H<sub>2</sub> (and/or  
15 D<sub>2</sub>), and other gases.

[0007] In current COIL systems, chlorine gas, with or without a diluent gas such as nitrogen or helium, reacts at low pressure with a solution of basic hydrogen peroxide (i.e., usually NaOH, KOH or other strong base mixed with hydrogen peroxide) to produce a gaseous flow of excited oxygen, also referred to  
20 as singlet delta oxygen or singlet molecular oxygen (designated as O<sub>2</sub><sup>\*</sup>, O<sub>2</sub>(<sup>1</sup>Δ), as well as by other symbols). This gaseous flow of singlet delta oxygen mixes (typically at speeds approaching or even exceeding the speed of sound) with iodine gas molecules (i.e., I<sub>2</sub>) generally mixed with a diluent gas such as nitrogen or helium, dissociating them and exciting the resulting iodine atoms (i.e., I), which lase  
25 at 1.315 μm. The major laser byproducts are various salts (e.g., NaCl or KCl), water, and heat. Exhaust from the COIL laser cavity is typically a mixture of gases at near ambient temperature, including nitrogen or helium, oxygen, and small amounts of chlorine, iodine, and water. The gas is recompressed, the small amounts of chlorine and iodine can be scrubbed from the output, and the resulting  
30 gas exhausted.

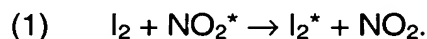
[0008] The intended operation of a conventional COIL system can be summarized as follows. The initial step is to generate the singlet delta oxygen. This is accomplished by providing a source of basic hydrogen peroxide, typically in liquid

form, and a source of molecular chlorine, typically in gaseous form. These two materials are then charged or injected into a singlet delta oxygen generator through appropriate manifold/conduit assemblies, respectively. The resulting exothermic reaction between the basic hydrogen peroxide liquid and the molecular chlorine gas produces the gaseous singlet delta oxygen, as well as several by-products, such as salt and heat. The heat can be removed by appropriate devices such as a heat exchanger, and the salt can be removed by appropriate devices such as a filter, if desired.

[0009] Once the gaseous singlet delta oxygen is generated, it is then charged or injected in flow form into a mixing nozzle at the appropriate time. The mixing nozzle has a throat portion which generally divides the mixing nozzle into a subsonic zone and a supersonic zone; that is, the flow of gaseous singlet delta oxygen is subsonic in one portion of the mixing nozzle and supersonic at the other portion of the mixing nozzle. The mixing of reactants is typically done in the subsonic zone, but their mixing can be done in other zones of the gain generator.

[0010] A molecular iodine generator is in communication with the mixing nozzle by an appropriate manifold/conduit assembly. At the appropriate time, gaseous molecular iodine is then charged or injected into the mixing nozzle in such a manner so as to partially or completely mix with the singlet delta oxygen gas flowing from the singlet delta oxygen generator. The mixing permits the singlet delta oxygen to dissociate some of the molecular iodine and thereby initiate the chain reaction dissociation by the product, excited atomic iodine.

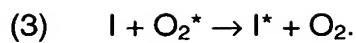
[0011] The primary reactions taking place in connection with the conventional COIL system are as follows:



[0012] That is, a mole of molecular iodine reacts with several moles (denoted by the symbol "N") of singlet delta oxygen to produce a mole of excited molecular iodine and several moles of molecular oxygen.



[0013] That is, a mole of excited molecular iodine reacts with a mole of singlet delta oxygen to produce two moles of atomic iodine and a mole of molecular oxygen.



[0014] That is, a mole of atomic iodine reacts with a mole of singlet delta oxygen to produce a mole of excited atomic iodine and a mole of molecular oxygen.



[0015] That is, a molecule of excited atomic iodine interacts with a photon and releases a second photon ( $h\nu$ ), thus producing a molecule of atomic iodine.

[0016] The singlet delta oxygen gas flow initially contacts the gaseous  
10 molecular iodine gas at subsonic speed; however, the singlet delta oxygen gas flow is quickly brought up to near supersonic or even supersonic speed (via appropriate devices such as a venturi) and is expelled out through the mixing nozzle into the area known as the laser cavity or laser gain region. It is in this area where the excited atomic iodine releases its photon. The released photons are then reflected  
15 between a set of mirrors, the first mirror being fully reflective, the second mirror being partially reflective. The reflected photons eventually form a laser beam, which is transmitted through the partially reflective mirror at a wavelength of  $1.315\mu\text{m}$ . Any remaining chemical species are removed from the laser gain region by a combination of exhaust assemblies and scrubber assemblies in order to avoid  
20 contamination of the laser's mirrors and to allow continuing flow of the laser chemicals so as to sustain the lasing process.

[0017] One particular application of chemical laser systems that is of significant interest is in space-based lasers (SBL's). As part of a ballistic missile defense system, SBL's have the potential of intercepting and destroying enemy  
25 missiles prior to them reaching their intended targets. An SBL system would achieve missile interception by focusing and maintaining a high powered laser on a target until it achieves catastrophic destruction. Because the SBL system typically requires very large amounts of laser power to achieve it's operational objectives, it is unlikely that an electrically driven laser system would be a practical source of  
30 power, at least for the foreseeable future. However, it is generally believed that the amount of energy needed for the sustained laser burst can be produced by currently available COIL systems.

[0018] Unfortunately, an SBL system employing a COIL system necessarily means that the COIL system would have to rely on the limited amount of chemical supplies on board the vehicle at the time of launch. However, the COIL system would require resupply of those particular chemicals, especially basic  
5 hydrogen peroxide, chlorine, iodine, and nitrogen, after the SBL has conducted it's missile destruction mission. As the SBL systems are to be deployed in orbit above the Earth, rapid and frequent resupply of these chemicals would be highly problematic even under ideal conditions, and would be especially difficult during and immediately after any type of prolonged ballistic missile exchange.  
10 Accordingly, current SBL system designs which employ COIL systems have no means of resupplying the chemicals required for COIL system operation. Thus, the resupply problem has been identified as a significant impediment to future development and deployment of the SBL system.

[0019] While the difficulty of resupply may not be as extreme as for an  
15 SBL system, there are numerous other applications for COIL lasers for which fuel resupply is complex, costly, and difficult. For examples, COIL lasers may be used in ground and airborne applications, where fuel resupply may be hindered by location and weight restrictions.

[0020] Therefore, there exists a need for a system for collecting,  
20 reprocessing and recycling the spent chemical species required by a COIL system, especially one that is used in conjunction with either a ground-, airborne-, or space-based laser weapon system, irrespective of the source of the spent chemical species.

## 25 BACKGROUND ART

[0021] U.S. Patent No. 3,992,685 discloses a chemical laser including a laser pump which is relatively lightweight with no moving parts. This produces a low pressure, regenerable, closed system for treating laser cavity exhaust gases to remove (i.e., pump) them from the system. The exhaust gases  
30 which emerge from the laser cavity of the chemical laser are pumped by reacting them preferably with titanium, titanium-zirconium alloys, zirconium, tantalum, etc. These gases include hydrogen, deuterium and their halides, the halogens, oxygen, CO<sub>2</sub>, nitrogen and H<sub>2</sub>O.

[0022] U.S. Patent No. 4,028,069 discloses that contaminants, such as water and hydrogen sulfide, are removed from hydrocarbon streams by the use of beds of solid adsorbents including molecular sieves. The adsorbents are regenerated by heating, with the heating being performed in a closed-loop operation wherein a small quantity of the hydrocarbon being treated is recycled in a closed-loop recirculation system comprising the adsorbent and a heater until the adsorbent reaches an effective regeneration temperature.

[0023] U.S. Patent No. 4,188,592 discloses a closed cycle chemical laser adapted for continuous wave operation. A first gas such as sulphur hexafluoride is decomposed by an electrical discharge means to provide at least some fluorine atoms which when combined with molecular hydrogen in a mixing chamber located upstream of and proximate to an optical power extraction chamber forms an excited laser species capable of stimulated emission to produce a continuous wave output beam. After passing through the optical cavity the effluent is purified by selective absorption and adsorption processes to eliminate the laser species from the effluent and to separate the hydrogen for recirculation back to the mixing chamber. The remaining effluent has its pressure increased, is supplemented with makeup feed gases and is recycled.

[0024] U.S. Patent No. 4,357,309 discloses an apparatus and method for generating on demand a gaseous product from a liquid phase reaction of one reactant in the solid phase at ambient room conditions and another reactant in the liquid phase at ambient room conditions. The reactants preferably are iodine crystals, and liquid tetrahydronaphthalene (THN), with the gaseous product being hydrogen iodide. The liquid phase reaction, in the preferred embodiment, is  $2I_2 + C_{10}H_{12} \rightarrow 4HI + C_{10}H_8$ , known per se. Preferably, THN is pumped from a reservoir to be sprinkled over the iodine crystals in another reservoir. Some iodine dissolves into the liquid THN, with the resulting solution then percolating through a reaction zone containing a heated, porous packing material. Heat is transferred to the solution, thereby promoting, i.e., driving the above reaction. The gaseous hydrogen iodide is then removed from the reaction zone; typically for direct use, for example, in a chemical laser.

[0025] U.S. Patent No. 5,974,027 discloses a high energy chemical laser capable of being operated in an aircraft to interdict and destroy theater

ballistic missiles. A key to the chemical laser of the invention is the use of individual chemical lasers whose individual photon energy outputs can be combined into a single high-energy laser beam.

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## SUMMARY OF THE INVENTION

[0026] The present invention provides a method for collecting, reprocessing, and recycling chemical species used in the operation of a chemical oxygen-iodine laser system. The method primarily includes: (1) collecting an amount of spent basic hydrogen peroxide containing aqueous potassium chloride; (2) converting the aqueous potassium chloride into water, molecular hydrogen, molecular chlorine, and aqueous potassium hydroxide; (3) combining the water and molecular hydrogen with an amount of molecular oxygen from the molecular oxygen source to form aqueous hydrogen peroxide; and (4) mixing the aqueous hydrogen peroxide with the aqueous potassium hydroxide to form basic hydrogen peroxide.

[0027] The features, functions, and advantages can be achieved independently in various embodiments of the present inventions or may be combined in yet other embodiments.

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## BRIEF DESCRIPTION OF THE DRAWINGS

[0028] The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

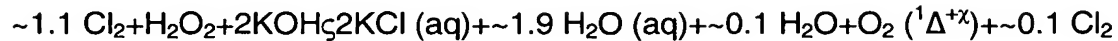
[0029] FIGURE 1 is a schematic illustration of a system for collecting spent basic hydrogen peroxide, converting same into molecular chlorine and fresh basic hydrogen peroxide, and recycling same back to the associated COIL system, in accordance with one embodiment of the present invention.

## DETAILED DESCRIPTION OF THE VARIOUS EMBODIMENTS

[0030] The following description of the various embodiments is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses.

[0031] In order to fully appreciate the features and advantages of the present invention, it is first necessary to understand the basic overall chemical

reaction which occurs during COIL operation. Simply stated, the overall reaction can be summarized as follows:



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**[0032]** In this equation, starting from the left hand side of the equation and progressing to the right, approximately 1.1 moles of molecular chlorine is combined with fresh basic hydrogen peroxide (BHP), which provides one mole of hydrogen peroxide and 2 moles of potassium hydroxide. This mixture is reacted together and produces spent BHP (i.e., 2 moles of potassium chloride (i.e., a salt) and approximately 1.9 moles of water in solution) as well as some of the laser mixing nozzle gaseous reactants (i.e., approximately 0.1 moles of gaseous water, 1 mole of molecular oxygen (in delta singlet and ground state forms) and approximately 0.1 moles of molecular chlorine which does not react with BHP).

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**[0033]** These gaseous reactants are then introduced into the laser mixing nozzle in the presence of molecular iodine (approximately 0.01 moles) and the diluent gas (e.g., 5 moles of molecular nitrogen). The diluent gas may also include heavy inert gases such as argon, krypton, and xenon, freon, freon substitutes, and other gases known to be non-reacting with the gases in the laser nozzle cavity but which are condensable or adsorbable in a sealed exhaust system (e.g., chlorine). As previously described, a laser beam is then generated, with the waste gases typically exhausted through a vacuum system or directly to space, in the situation where the COIL system is space-based.

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**[0034]** Thus, the present invention is primarily concerned with conserving the available supplies of fresh BHP and molecular chlorine in a space-based or other COIL system, where resupply of any chemicals is difficult. Furthermore, the present invention is also concerned with recycling, where possible, any spent supplies of BHP in order to generate fresh BHP, as well as recycled molecular chlorine.

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**[0035]** Referring to FIG. 1, there is shown a schematic illustration of an illustrative system 10 for collecting spent basic hydrogen peroxide, converting same into molecular chlorine and fresh basic hydrogen peroxide, and recycling

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same back to the associated COIL system, in accordance with one embodiment of the present invention.

[0036] In this view, the system 10 includes a source of molecular chlorine 12 and a source of basic hydrogen peroxide (BHP) 14 which are combined together to produce spent BHP, which is a solution containing aqueous potassium chloride that includes potassium chloride (KCl) and water (H<sub>2</sub>O). This spent BHP is then collected in a collection system 16 (e.g., a storage tank) for later use, as will be described herein.

[0037] The remaining COIL laser nozzle reactants 18 (i.e., water, singlet delta oxygen and molecular chlorine) are then combined with a source 20 of molecular iodine carried in a molecular nitrogen (or other compound) diluent gas in the COIL laser mixing nozzle 22, whereupon a laser beam 24 is generated with the waste laser gases 26 exhausted into space, as would be the case if the COIL system was associated with an SBL system, or through a vacuum system to the ambient atmosphere. The source 20 of molecular iodine and molecular nitrogen can be resupplied through a storage system 20A which is in fluid communication with the source 20 of molecular iodine and molecular nitrogen through an appropriate conduit or pipe 20B.

[0038] To begin the recycling process, the spent BHP is transported from the storage system 16 via an appropriate conduit or pipe 28 to a first processing system 30, which is preferably a system which employs electrolysis to treat this aqueous salt, potassium chloride. The electrolysis system can be electrically powered using solar power, for example from the vehicle's solar panels, or some other source of electrical power. The spent BHP is then converted, preferably via electrolysis, into three main constituent chemical species: molecular hydrogen, aqueous potassium hydroxide, and molecular chlorine.

[0039] The molecular chlorine is the simplest chemical specie to treat, in terms of recycling, in that only residual moisture, if any, needs to be removed therefrom. In order to accomplish this task, the molecular chlorine is transported via an appropriate conduit or pipe 32 to a drying system 34, wherein any moisture (e.g., water) is removed through any number of conventional means (e.g., adsorption). The drying system 34 can be electrically powered using solar power, for example from the vehicle's solar panels, or some other source of electrical power. The result

is moisture-free molecular chlorine gas which is then transported via an appropriate conduit or pipe 36 back to the molecular chlorine source 12, thus preserving and conserving the amount of molecular chlorine that is required by the COIL system associated with a ground-, airborne-, or space-based laser weapon system.

5           **[0040]**       The generation of recycled fresh BHP is slightly more complicated than the generation of recycled molecular chlorine. Water and the molecular hydrogen formed by the first processing system 30 is transported via an appropriate conduit or pipe 38 to a second processing system 40 which is intended to produce hydrogen peroxide. Preferably, the second processing system 40  
10 produces the hydrogen peroxide utilizing an electrogeneration system, i.e., uses electrical power to produce or generate the hydrogen peroxide. In accordance with a highly preferred embodiment of the present invention, an electrochemical cell is used to generate the hydrogen peroxide. The second processing system 40 can be electrically powered using solar power, for example from the vehicle's solar panels,  
15 or some other source of electrical power.

**[0041]**       In order to generate the hydrogen peroxide, the molecular hydrogen must be combined with molecular oxygen (either directly or through reaction first to water and then by oxidation to hydrogen peroxide) which is supplied from a molecular oxygen source 42 which is in fluid communication with the second  
20 processing system 40 transported via an appropriate conduit or pipe 44. Depending on the process selected, potassium hydroxide may also be used to facilitate production of hydrogen peroxide.

**[0042]**       In general, it is preferred to utilize the molecular hydrogen and molecular oxygen produced or recovered elsewhere in the system 10. Depending  
25 on the methodology employed, the production of fresh BHP can be done by a direct combination of molecular hydrogen and molecular oxygen or by combining molecular hydrogen and some of the molecular oxygen to form water, and then by oxidation of water to hydrogen peroxide with the remaining molecular oxygen.

**[0043]**       Direct oxidation can be done over a suitable catalyst or by use  
30 of a pair of chemicals that are cyclically reduced and oxidized, producing hydrogen peroxide as the net product.

**[0044]**       Oxidation of water can be done over a catalyst or by use of an electrochemical cell. Even when the molecular hydrogen and molecular oxygen are

reacted directly, generally water is required as the mediator and carrier for the hydrogen peroxide product.

[0045] The hydrogen peroxide can also be made in an aqueous acidic or basic medium, in which case it may be necessary to provide a source of acid  
5 (base is of course readily available from the prior process which produced potassium hydroxide).

[0046] Producing acid is probably best accomplished by reacting molecular chlorine with some of the molecular hydrogen (forming hydrogen chloride, which dissolves to form hydrochloric acid) or with water to form a mixture  
10 of hydrochloric acid and hypochlorous acid.

[0047] In cases in which hydrogen peroxide is being made in basic medium, the potassium hydroxide is fed into a hydrogen peroxide producing reactor. Achieving the desired ratio of hydrogen peroxide to potassium hydroxide may require that some of the potassium hydroxide be reacted with hydrochloric acid  
15 to re-convert it to potassium chloride.

[0048] The processing of the aqueous potassium chloride, as well as the production of hydrogen peroxide, may require additional water, which can be separately removed from the spent BHP.

[0049] Once the hydrogen peroxide is produced, it is then transported  
20 via an appropriate conduit or pipe 46 to a mixer system 48 where it is combined, in proper stoichiometric ratios, with the aqueous potassium hydroxide which is also transported via an appropriate conduit or pipe 46 to a mixer system 50.

[0050] When the hydrogen peroxide and the aqueous potassium hydroxide are finally mixed the result is fresh BHP, which is then transported to the  
25 fresh BHP source 14 via an appropriate conduit or pipe 52, thus preserving and conserving the amount of fresh BHP that is required by the COIL system associated with an SBL system.

[0051] In this manner, a ground-, airborne-, or space-based laser weapon system employing the modified COIL system of the present invention can  
30 carry the same amount of supply chemicals, such as molecular chlorine and fresh BHP, as a conventional COIL system and can operate for a longer period of time and execute more laser burst operations before needing to be resupplied.

[0052] Those skilled in the art can now appreciate from the foregoing description that the broad teachings of the present invention can be implemented in a variety of forms. Therefore, while this invention has been described in connection with particular examples thereof, the true scope of the invention should not be so limited since other modifications will become apparent to the skilled practitioner upon a study of the drawings, specification and following claims.

[0053] While various preferred embodiments have been described, those skilled in the art will recognize modifications or variations which might be made without departing from the inventive concept. The examples illustrate the invention and are not intended to limit it. Therefore, the description and claims should be interpreted liberally with only such limitation as is necessary in view of the pertinent prior art.